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Alkaline Battery Division

GULTON INDUSTRIES, INC.

Metuchen, N. J.

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DESIGN, DEVELOPMENT AND MANUFACTURE

OF STORAGE BATTERIES

FOR FUTURE SATELLITES IV

REPORT NO. 4

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION - (NASA CONTRACT NO. NAS 5-509)

~~FOURTH QUARTERLY PROGRESS REPORT~~,

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I. ABSTRACT

16013

A considerable number of VO-6 HS cells have been fabricated in the pilot line which was established during the period of this contract.

The use of strict quality control techniques in the pilot plant has resulted in a decrease in the number of rejections each month during the quarter. Failures in manufacture have been analyzed and work is being done to correct the weak spots.

The procedure for adding helium for leak detection is described. The electrical and mechanical checkout procedures to which each cell is subjected are described.

The thermal and electrical characteristics of VO-6 HS cells were further studied.

The use of thinner electrodes was studied to see if an improvement in watt-hour per pound output was achievable.

AUTHOR

II. PRODUCTION OF VO-6 HS CELLS

To date, the cells listed in the following Table I have been delivered to NASA during this reporting period. Cells up to serial number 292 were covered in the Third Quarterly Report. Some of these cells were delivered under Contract NAS5-1583.

TABLE I

Test History of VO-6 HS Cells

Delivered to NASA

Cell Serial No.		Overcharge Rate ma	Voltage	Press.	Capacity 3 Amp. to 1.0 Volt	Cycles*	Short Test O.C.V. After 24 hrs.
252		500	1.43	19	6.7	24	
293	Potted	500	1.50	4	6.7	10	
294	Potted	500	1.45	24	6.7	10	
295	Potted	500	1.45	50	6.2	10	
296	Potted	500	1.50	32	6.2	10	
297	Potted	500	1.45	35	6.6	10	
298	Potted	500	1.45	45	6.4	10	
304		500	1.45	20	6.75	10	1.20
308		500	1.45	9	8.73	10	1.20
316		500	1.45	8	9.00	10	1.20
317		500	1.45	7	9.00	10	1.20
326		500	1.43	12	7.50	10	1.20
327		500	1.43	13	6.48	10	1.20
328		500	1.43	12	6.00	10	1.20
329		500	1.43	13	6.70	10	1.20
332		500	1.40	5	6.00	10	1.20
333		500	1.43	14	7.50	10	1.20
334		500	1.43	12	7.50	10	1.20
335		500	1.43	10	7.73	10	1.20
336		500	1.43	14	6.75	10	1.20
337		500	1.43	3	7.50	10	1.20
338		500	1.43	4	7.74	10	1.20
340		500	1.43	11	7.50	10	1.20
341		500	1.43	26	6.00	10	1.20
342		500	1.43	12	6.00	10	1.20
343		500	1.45	20	6.00	10	1.20
344		500	1.43	18	6.00	10	1.20
346		500	1.43	36	6.00	10	1.20
347		500	1.45	20	6.00	10	1.20
348		500	1.43	7	6.48	10	1.20
349		500	1.43	9	6.75	10	1.20
350		500	1.43	17	6.00	10	1.20
351		500	1.43	9	6.10	10	1.20
365		500	1.43	10	7.74	10	1.20
366		500	1.43	6	6.24	10	1.20
367		500	1.43	20	6.10	10	1.20
373		500	1.43	12	6.00	10	1.20
377		500	1.43	4	6.00	10	1.20
379		500	1.43	15	7.74	10	1.20
380		500	1.45	20	6.00	10	1.20
381		500	1.45	24	7.98	10	1.20
382			1.43	13	6.99	10	1.20
393		600	1.44	17	6.20	10	1.20
405		600	1.50	7	7.50	10	1.20
408		600	1.48	16	6.33	10	1.22

TABLE I (Cont'd)

Cell Serial No.	Overcharge Rate ma	Overcharge Voltage	Overcharge Press.	Capacity 3 Amp. to 1.0 Volt	Cycles *	Short Test O.C.V. After 24 hrs.
417	600	1.50	35	6.48	10	1.21
433	600	1.50	49	7.14	10	1.20
435	600	1.42	55	7.50	10	1.20
449	600	1.50	49	7.44	10	1.20
456	600	1.50	52	6.10	10	1.20
460	600	1.45	77	6.90	10	1.20
467	600	1.50	50	6.15	10	1.20
470	600	1.45	63	6.00	10	1.20
473	600	1.50	40	6.10	10	1.20
477	600	1.40	39	6.85	10	1.20
478	600	1.45	8	7.40	10	1.20
479	600	1.50	19	6.75	10	1.20
480	600	1.40	16	6.55	10	1.20
484	600	1.44	36	7.65	10	1.20
485	600	1.45	45	6.80	10	1.20
486	600	1.44	43	7.35	10	1.20
487	600	1.45	19	7.35	10	1.20
488	600	1.44	40	7.35	10	1.20
489	600	1.45	8	7.35	10	1.20
490	600	1.40	26	7.30	10	1.20
491	600	1.42	24	7.05	10	1.20
493	600	1.40	30	6.75	10	1.20
494	600	1.40	32	7.00	10	1.20
495	600	1.40	23	7.50	10	1.20
496	600	1.40	52	7.75	10	1.20
497	600	1.40	50	7.50	10	1.20
499	600	1.45	20	7.80	10	1.20
500	600	1.40	37	7.50	10	1.20
501	600	1.40	51	7.50	10	1.20
503	600	1.42	45	8.00	10	1.20
507	600	1.46	25	7.85	10	1.20
508	600	1.40	32	7.75	10	1.20
509	600	1.45	24	7.75	10	1.20
511	600	1.40	44	6.35	10	1.20

* Cycle consists of 90 minute charge at 1.5 Amp., 30 minute discharge at 3.0 Amp.

Since the production of these cells has been a pilot plant function, and since the pilot plant has been undergoing changes to produce these cells, a discussion of the changes in structure of the cells and changes in the techniques of manufacture are discussed in Section III, "Establishment of a Pilot Line for Fabrication of Hermetically Sealed Cells."

III. ESTABLISHMENT OF A PILOT LINE FOR FABRICATION OF HERMETICALLY SEALED CELLS (Phase II)

The effort concentrated in the pilot plant during this reporting period was directed largely at cell production and the refinement of the pilot plant processes. The point at which the all-welded cell was introduced was very significant to the entire operation of the pilot plant as well as to the reliability of the cells being produced.

Table II is a compilation of the rejections of cells showing the percentage of rejects for the various causes up to the final checkout of cells. The figures include the losses due to malfunction of the electrode such as shorts, low capacity, high pressure . . . etc. It will be noted that there was a radical improvement in August because of the change to the all welded construction of the cells. Subsequent months show very significant improvement each month as a result of refinement of the processes and training of personnel.

TABLE II

Rejection Rates For VO-6 HS Cells During Manufacture

Reasons For Reject	Percentages June-July	August	September	October
Leaks Positive Terminal	52.2	5.4	6.5	.9
" Negative "	5.4	4.0		
" Seam	10.9	6.8		
" Seal	1.0			1.8
" Pinch Tube		5.4	8.1	
" Unidentified		6.8	6.5	
Shorts	15.2	17.7		.9
Cracked Ceramic		1.3		
Low Capacity	3.3	4.0		9.2
High Pressure				9.2
Other		1.3	8.1	5.5
Total % Reject	88.0	52.7	29.2	27.5
Total % Shipped	12.0	47.3	70.8	72.5

The rejection percentages in Table II are broken down so that the mode of failure is indicated. Obviously, maximum effort is being concentrated upon those facets of the manufacture giving the highest reject rates in order to lower the rates and improve the reliability of the completed product.

The current methods of manufacture make maximum use of the heliarc welding facilities to manufacture an improved VO-6 HS Cell. Besides making the final closure of the cell and sealing the pinch tube, the heliarc is used to join the negative comb suprort to the negative comb and to join the negative terminal to the cover. Some difficulty has been encountered in the latter operation wherein cracking of the weld has occurred. Indications at this time are that the covers had been tumbled in an aluminum oxide agent which contaminated the surface of the cover and resulted in a burning action within the weld. This hypothesis is borne out by the fact that the cracked areas could not be fused over and that treatment of the surface with dilute KOH solution or mechanical abrasion resulted in improved welds. Specific warnings not to tumble these parts have been issued and cells are being fabricated by resistance welding of the terminal to the cover until such time as this problem is completely resolved.

A simple system of introducing helium into cells prior to final pinching and welding of the tube has been introduced into production line procedure. Basically, the following procedure is used:

a) A chamber, calculated to hold the correct volume of helium at one atmosphere absolute, is evacuated and filled with helium.

b) A cell, which is in vacuum, is connected to the chamber and a valve opened to allow the helium to flow into the cell.

c) Pure oxygen is then used to bring the internal pressure of the cell up to atmosphere so that there will be no mass transfer of gases while the pinch-tube is being welded.

d) The pinch tube is welded closed, and the complete cell is checked for leaks by placing it in a bell jar and scanning the volume of the jar for traces of helium.

This operation in conjunction with the final electrical check-out of all cells gives assurance of the reliability of the sealing of cells prior to shipping. Subsequent to shipment, these cells may be checked for leakage using a mass spectrometer leak detector. If a gross leak should occur, the vapor pressure within the cell would make it impossible to evacuate the test chamber, while small leaks would be detectable by the leakage of helium.

The final check-out procedure for the VO-6 HS Cell, from the point where the cover is welded on is as follows:

a) The complete cell is fixtured under a bell jar on the Veeco mass spectrometer. The cell is evacuated and backfilled with helium to a pressure of 20 psia while the bell jar is completely evacuated. The bell jar is then scanned for the presence of helium; which, if present, must have leaked from within the cell. If any helium is detected the cell is rejected.

b) Good cells are carefully filled with a measured quantity of electrolyte and the pressure gauge and valve are installed by means of a collet fitting on the pinch tube.

c) With the vent valve opened, the cells are discharged at 600 ma. The vent is closed and the cell evacuated to 30" Hg vacuum. The cells are then pressurized with oxygen to 50-55 psig and allowed to stand for one hour. The cell pressure must remain 30 to 55 psi for this length of time.

d) Cells are charged at 600 ma (C/10) for at least 24 hours while checking cell pressures. At the end of this run a solution of phenolphthalein is sprayed over seals and welds to detect any seal break-downs under operation. The spray is an intermediate check which permits the seals to be monitored while the cells are on electrical test, without necessitating the removal of cells for helium leak detection.

e) The cells are now given 20 hours of cycling at a 1.2 ampere 90 minute charge followed by a 3 ampere 30 minute discharge. At the end of a final charge cycle a C/10 charge rate is established for 8 hours after which cells are discharged for capacity at 3 amperes (C/2) to an end voltage of 1.0. The C/2 rate and the 1.0 Volt end potential have been adopted as the standards for rating the capacities of hermetically sealed cells at the Alkaline Battery Division of Gulton Industries, Inc.

f) At this point the helium is added to the cell as previously outlined, the pinch tube closed and welded, and the cells retested for helium leakage. The cells are now complete except for the final short test.

g) Cells are shorted for 16 hours, charged for 5 minutes at C/10, held on open circuit for 24 hours, and then checked for open circuit voltage. The open circuit voltage must be at least 1.10 volts for a cell to pass this test.

Upon successful completion of the above steps, cells are considered ready for shipment.

IV. RESEARCH AND DEVELOPMENT (Phase III)

A. HEAT TRANSFER

Cells have been fabricated with the necessary instrumentation to study the heat transfer characteristics of the VO-6 HS cell. The instrumentation consists of a thermocouple placed within the electrode stack, near its geometric center, and 24 thermocouples welded to the exterior surface of the cell case so that the temperature pattern at the surface may be studied.

The insertion of the internal thermocouple is a very difficult operation, requiring the removal of material from the center plate of the stack to make room for the thermocouple and its leads. A cell fabricated in this manner has a laboratory life expectancy of only 2 to 4 weeks.

The tests are being conducted in an air atmosphere in a controlled temperature chamber which maintains an ambient of 80°F on the cells. Several satisfactory cells with thermocouples were fabricated and some preliminary tests have been completed.

The preliminary data, taken on a 32 hour run at an 0.25 ampere charge rate and an 80°F ambient temperature shows an internal temperature of 86°F and a skin temperature of 83°F. The skin temperature of these cells shows a very uniform temperature; whereas, larger cells were found to have a higher temperature at the point corresponding to the center of the electrode stack.

Intentions are to completely survey the temperature distribution of these cells at 1/4 amp. overcharge, 1/2 amp. overcharge, 3/4 amp. overcharge, and 1 amp overcharge under various different ambient conditions of temperature, vacuum and heat sink.

Various methods of removing the heat from cells have been investigated. Since, on other tests, we have found that 80% of the heat generated within the cell is taken out through the largest faces of the cell; we have been working with the application of heat sinks to these areas.

The design of the VO-6 HS cell, having the negative element of the electrode grounded to the case through the negative terminal, and having the outer plates of the electrode stack in intimate contact with the cell case wall, is very conducive to the removal of heat through the wide faces of the cell. The fact that the cells must be restrained in this direction makes it easy to apply heat sinks with enough normal pressure to insure intimate contact with the case, and consequently a large area for heat transfer may be obtained.

B. ELECTRICAL CHARACTERISTICS OF THE VO-6 HS CELL

A group of four (4) cells have been given some preliminary testing at 120°F to 125°F. These cells, numbered 138, 140, 143, 146, were checked for capacity at room temperature at the C/2 discharge rate and were found to have capacities of 7.59, 7.50, 7.59, and 7.50 A.H. respectively.

Figure 1 shows the charge curves for cell #146 at 750 ma and 3 amperes. These curves are typical of the curves obtained for all four cells.

Figures 2, 3, 4 and 5, are the discharge curves for the cells following the various lengths and rates of charge shown.

It is apparent that at elevated temperatures the charge efficiency of the cell is poorer than at 77°F. It has also been observed that charge efficiency is poorer at low charge rates. Note, however, that after extended periods of charge the cells do reach their full capacity. This means that in satellite use, continuous extended overcharge during periods of extended sunlight, will recharge cells even at low charge currents and high temperatures.

It has also been observed that while it may take a long time for a cell to become charged at 50 ma, if the cell had been previously charged at a higher rate it will maintain its full charge when trickled at 50 ma. Measurements were made on a fully charged cell which had been trickled at 50 ma and after 11 days full capacity was still available on discharge. It remains to be determined what minimum trickle current will maintain a VO-6 HS cell fully charged and for how long.

C. STUDY OF THIN PLATES

Two special 5 plate laboratory cells were fabricated from specially prepared thin sintered plates. The plates were .025 inches thick, which is 73.5% of the thickness of our standard plates which are .034 inches thick. Under comparable conditions of temperature and discharge rate a standard plate of equivalent area gives 1.2 to 1.5 ampere hours capacity. The following Table III shows the capacities obtained from thin plates.

TABLE III

Run	Cell	Rate, Amp	Capacity, A.H.
1	A	1	.835
	B		.835
2	A	1	.835
	B		.835
3	A	1	.866
	B		.884
4	A	1	.900
	B		.900
5	A	.5	1.06
	B		1.06

The capacities obtained correspond to 75 to 77 percent of the standard plate. Based on the volume of the plate there is an apparent gain of available capacity of 2 to 4 percent. It does not follow necessarily that a lighter cell could be fabricated from the thin plates due to the fact that more layers of separator would be used. As an example, consider the VO-6 HS cell:

Using Standard Plates

9 pos. plates @ .034	=	.306
10 neg. plates @ .032	=	.320
20 thicknesses of separator @ .007	=	.140
		.766 Total pack thickness

Using Thin Plates

Assume capacity is 77% that of standard plate; then 11.7 positive plates would be required, which must be increased to 12 since plates cannot be divided.

12 pos. plates @ .025	=	.300
13 neg. plates @ .025	=	.325
26 thicknesses of separator @ .007	=	.182
		.807 Total pack thickness

It may be seen that the ratio of the efficiencies of thin plates to thick plates must be very great before it becomes economic to use the thinner plate. Studies of thicker sintered plates for increased weight efficiency of sealed cells should be undertaken to determine their feasibility.

V. CONCLUSIONS

1. Fabrication of Cells

The fabrication of cells is proceeding with steadily decreasing rejections of parts and cells during processing. The fact that successful cells are being produced at increasing rates with fewer rejects and more stringent quality control, indicates that the reliability of the product is being steadily improved.

2. Establishment of a Pilot Line

The pilot line, for producing sealed nickel cadmium cells for satellite applications, is fulfilling its purpose and producing cells in increasing quantities. This line is constantly being improved as experience in the processes results in modification of parts and techniques.

3. Research and Development

a. Heat Transfer

The VO-6 HS cell, from preliminary data available, appears good from the standpoint of heat dissipation. The temperature differential between inside of cell and outer walls is about $3^{\circ}F$ for a 1/4 amp. charge.

b. Electrical Characteristics of the VO-6 HS Cell

Nickel cadmium cells must be charged at a high rate at elevated temperatures in order to obtain best charge efficiency.

c. Thin Plates

The use of thin plates will increase the efficiency of a cell to some extent, but the indications are that the gain would not offset the additional weights incurred by the of construction. A more extensive testing program should be undertaken to determine the optimum plate thickness for sealed cells. This might actually be thicker than the plate now being used.

VI. PROGRAM FOR NEXT PERIOD

It is contemplated that this contract is to be extended for a period of another year. The effort will be concentrated on completing the pilot plant and continuing R & D on the hermetically sealed nickel-cadmium cell

During the next period work will be concentrated on:

A. Thermal Considerations in Large Size Cells up to 50 Ampere-Hours

B. Heat Transfer from Cell Surfaces to Heat Sink and Environment.

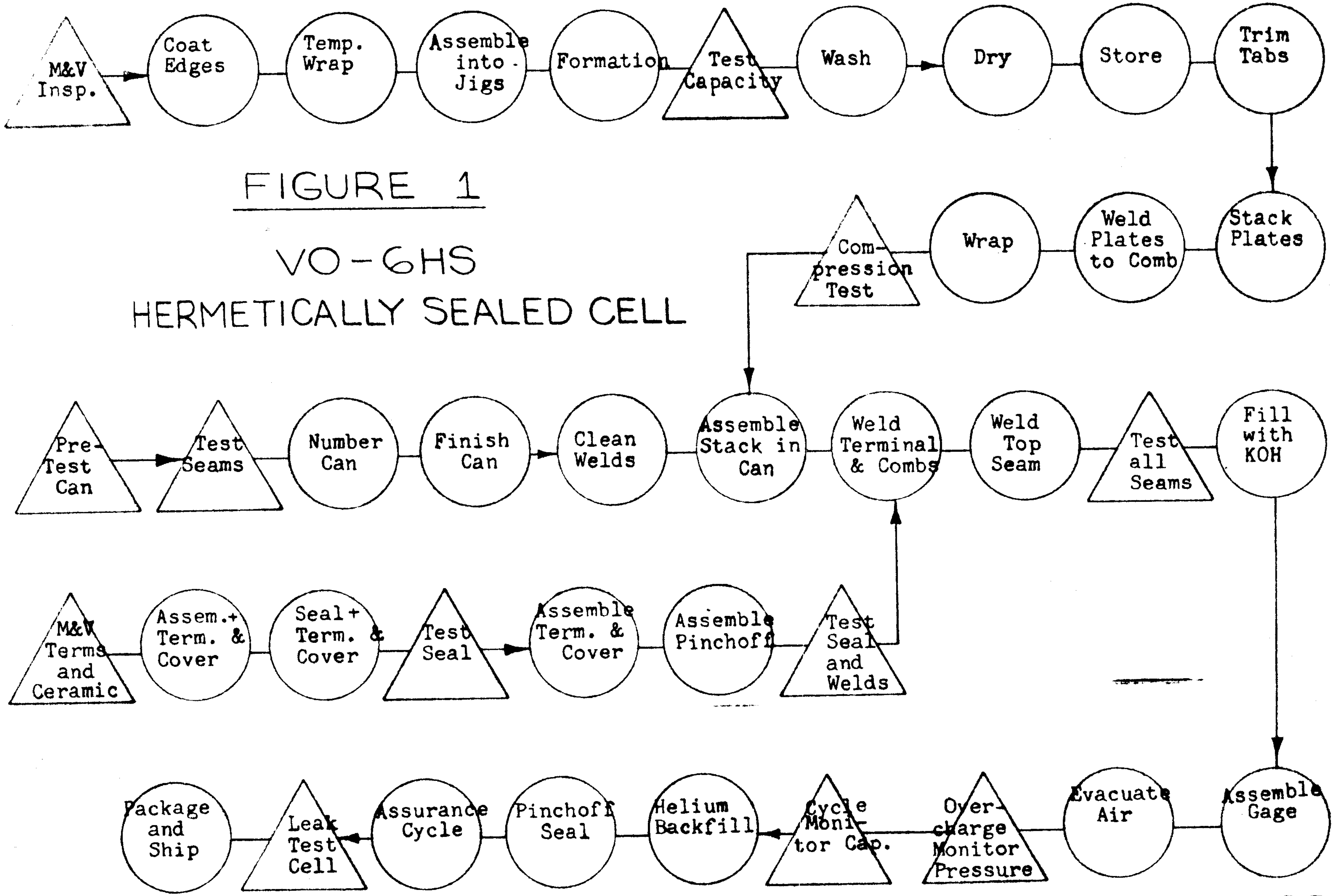

FIGURE 1

VO-6HS

HERMETICALLY SEALED CELL

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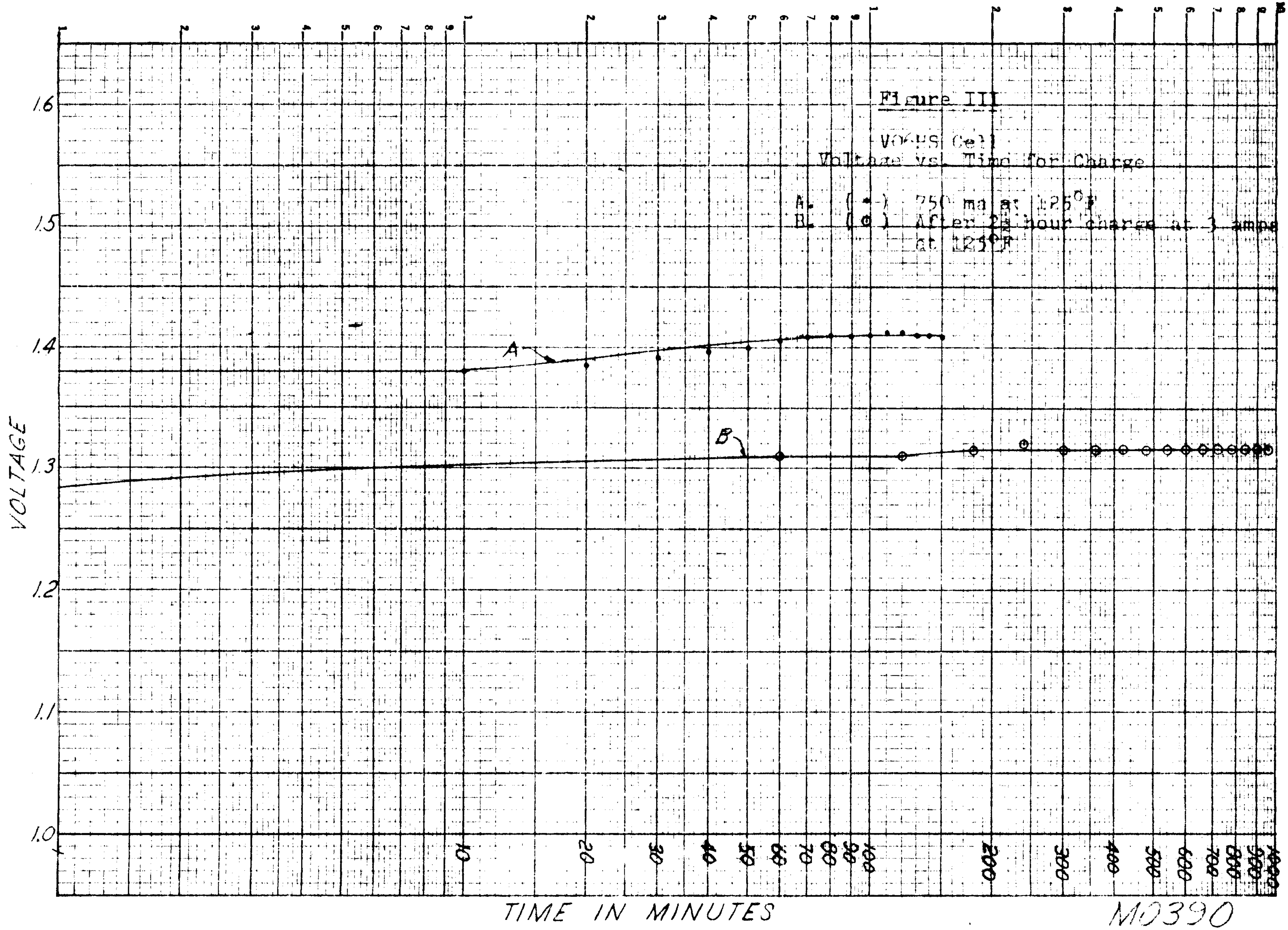


Figure III
VO-HS Cell
Voltage vs. Time for Charge
A. (•) 750 ma at 125°F
B. (o) After 24 hour charge at 3 amps at 125°F
A
B
VOLTAGE
1.6
1.5
1.4
1.3
1.2
1.1
1.0
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000
TIME IN MINUTES

M0390

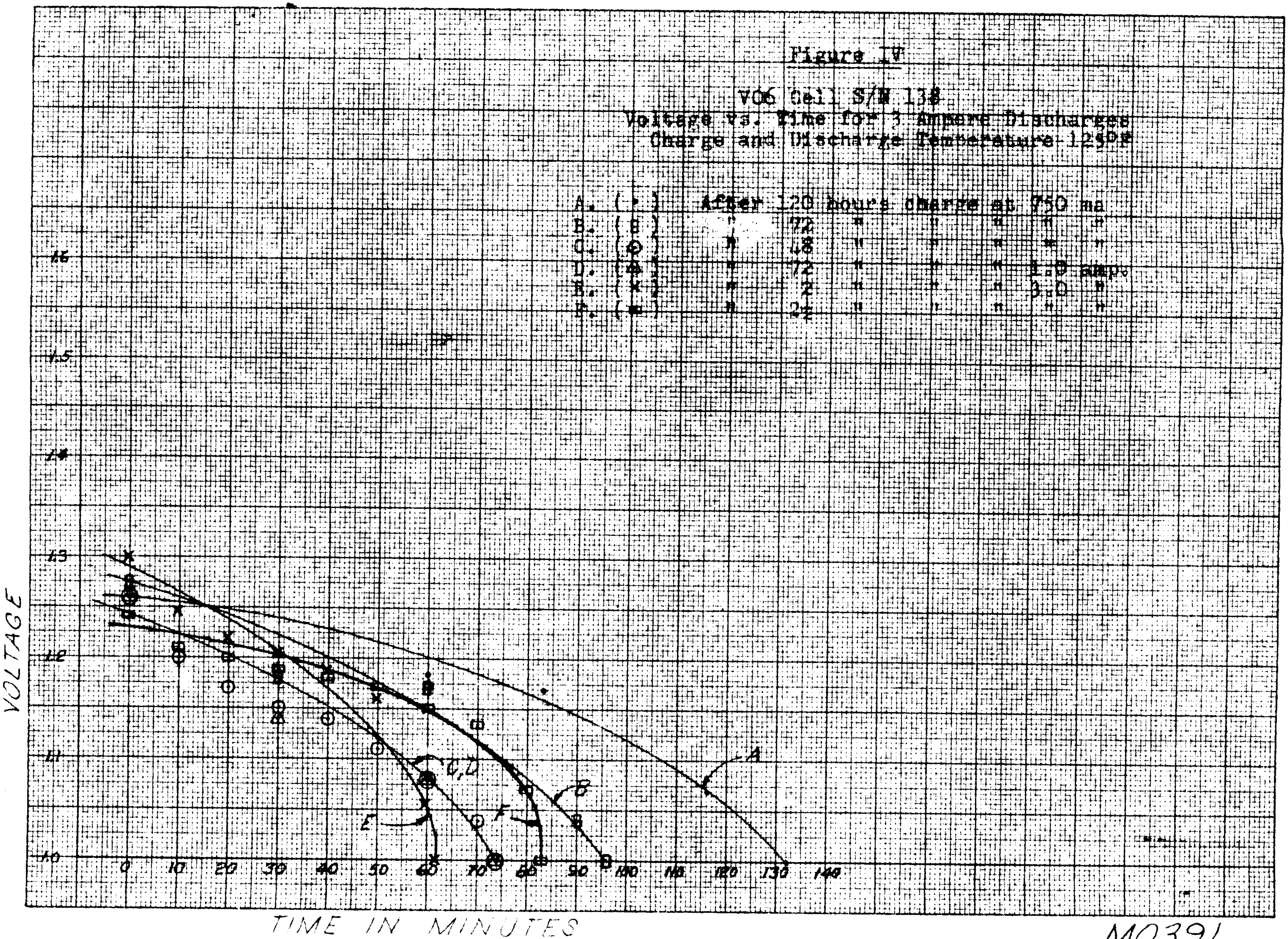
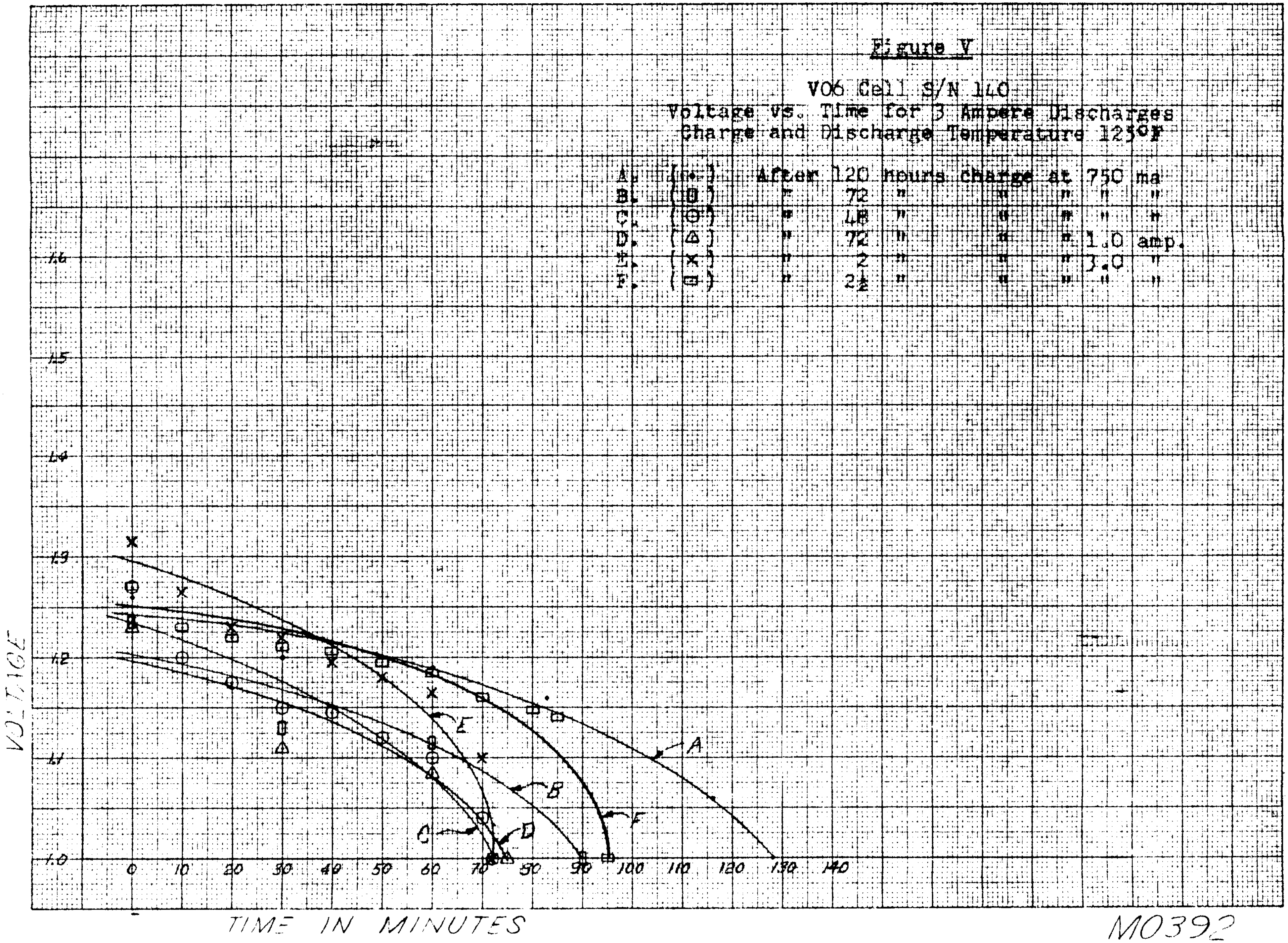


Figure IV
VO6 Cell S/N 138
Voltage vs. Time for 3 Ampere Discharges
Charge and Discharge Temperature 125°F
A. (•) After 120 hours charge at 750 ma
B. (⊞) " 72 " " " " "
C. (⊕) " 48 " " " " "
D. (⊕) " 72 " " " 1.0 amp.
E. (X) " 2 " " " 3.0 "
F. (⊞) " 2½ " " " " "
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
A
B
C,D
E
F
VOLTAGE
TIME IN MINUTES

M0391



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K+E 10 X 10 TO THE CM. KEUFFEL & ESSER CO. 359-14G

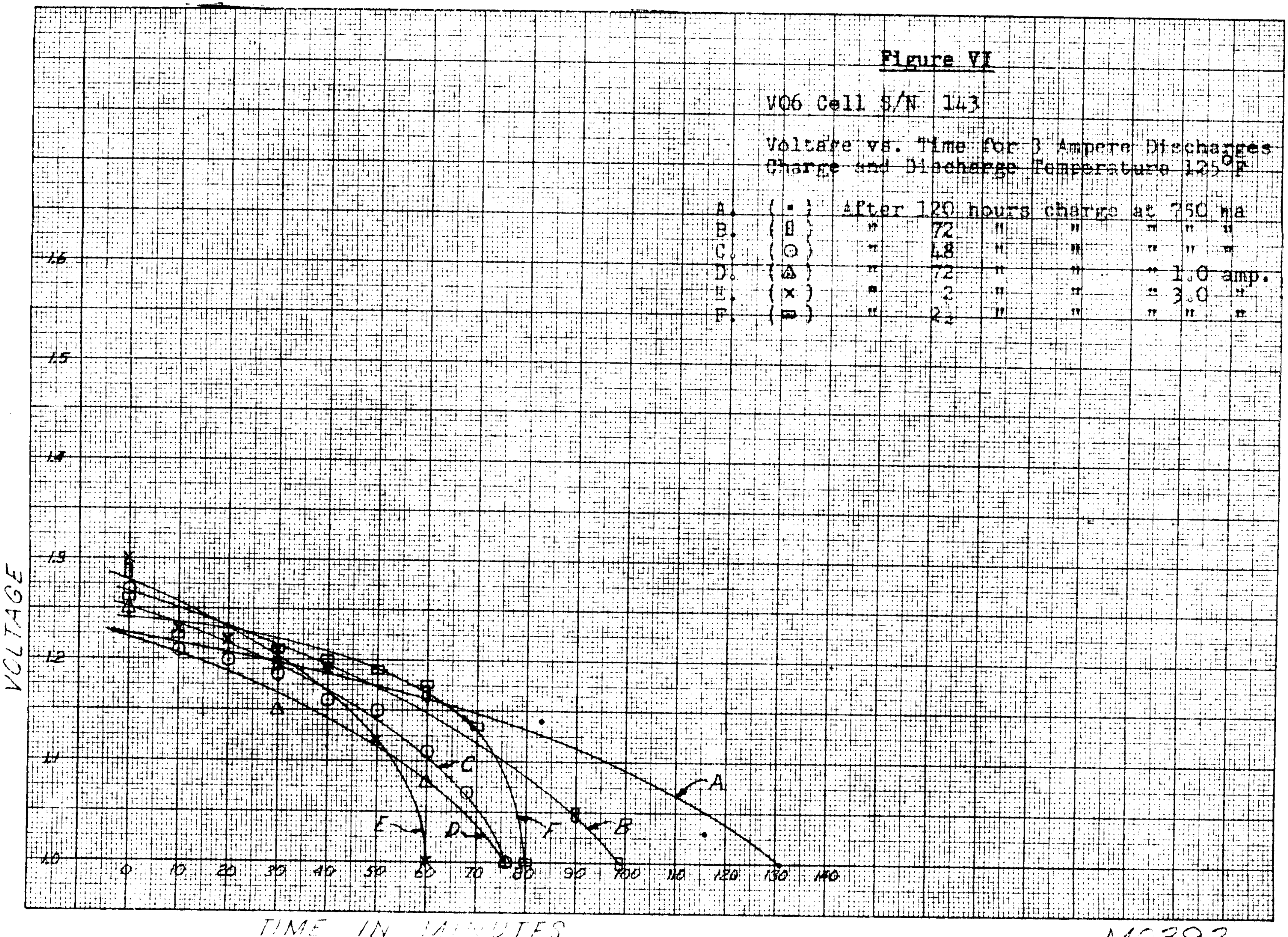


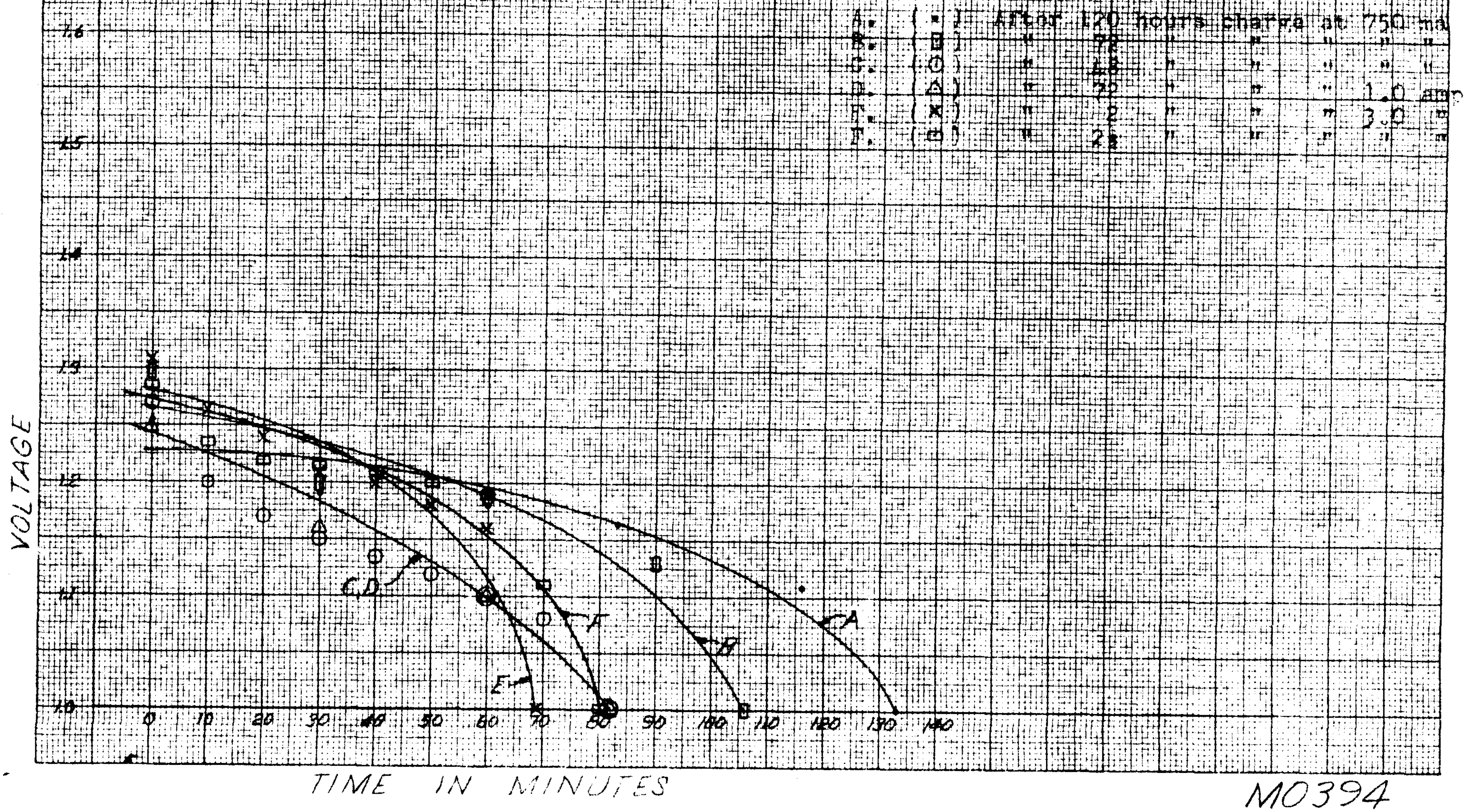
Figure VI
V06 Cell S/N 143
Voltage vs. Time for 3 Ampere Discharges
Charge and Discharge Temperature 125°F
A. (•) After 120 hours charge at 750 ma
B. (▫) " 72 " " " " "
C. (⊙) " 48 " " " " "
D. (△) " 72 " " " 1.0 amp.
E. (×) " 2 " " " 3.0 "
F. (▫) " 2 " " " " "
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
A
B
C
D
E
F
VOLTAGE
TIME IN MINUTES

M0393

FIGURE VII

V06 Cell S/N 146

Voltage vs. Time for 3 Ampere Discharges
Charge and Discharge Temperature 125°F



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